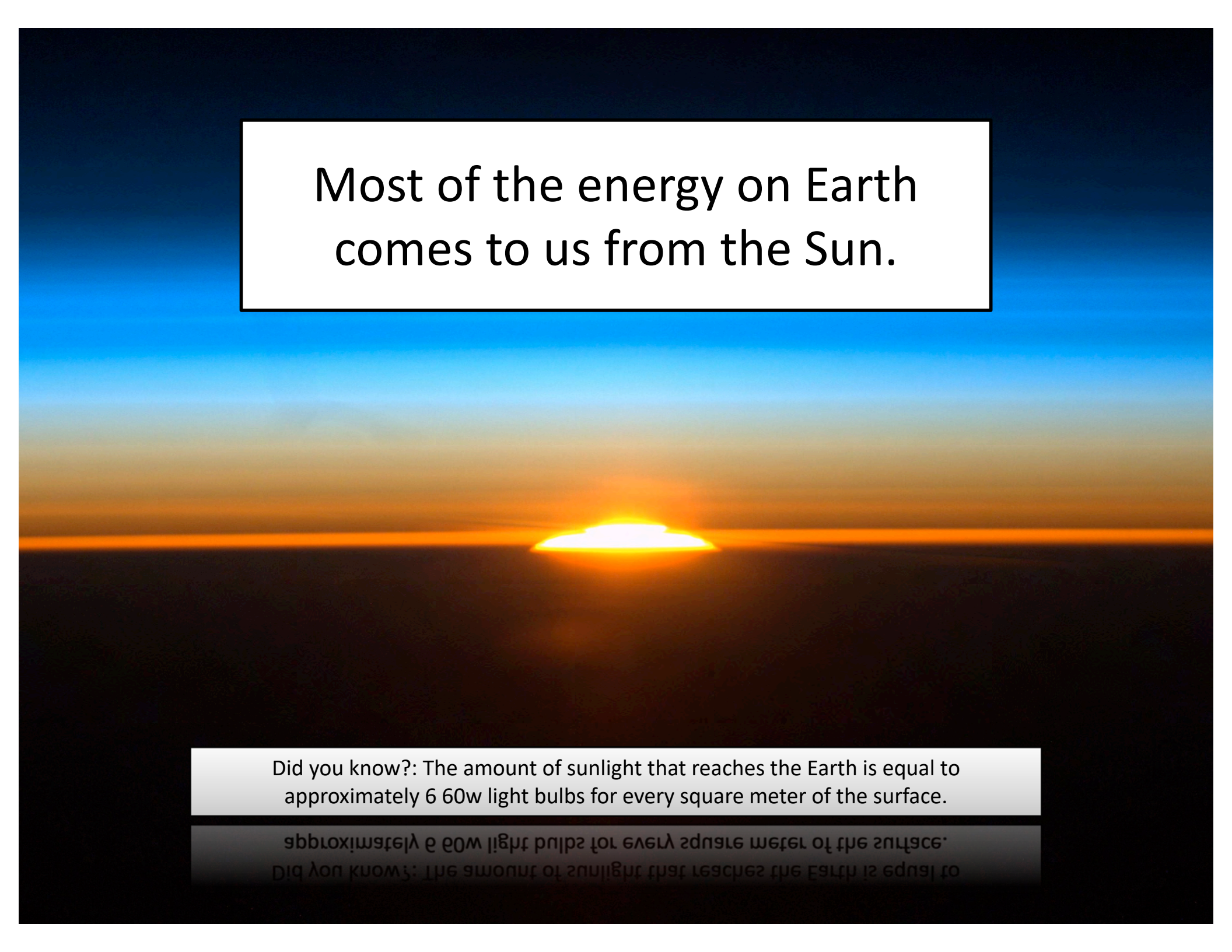


A satellite image of Earth from space, showing the Americas and surrounding oceans. The text "Earth's Energy Budget: A Story" is overlaid in the center.

# Earth's Energy Budget: A Story





Most of the energy on Earth  
comes to us from the Sun.

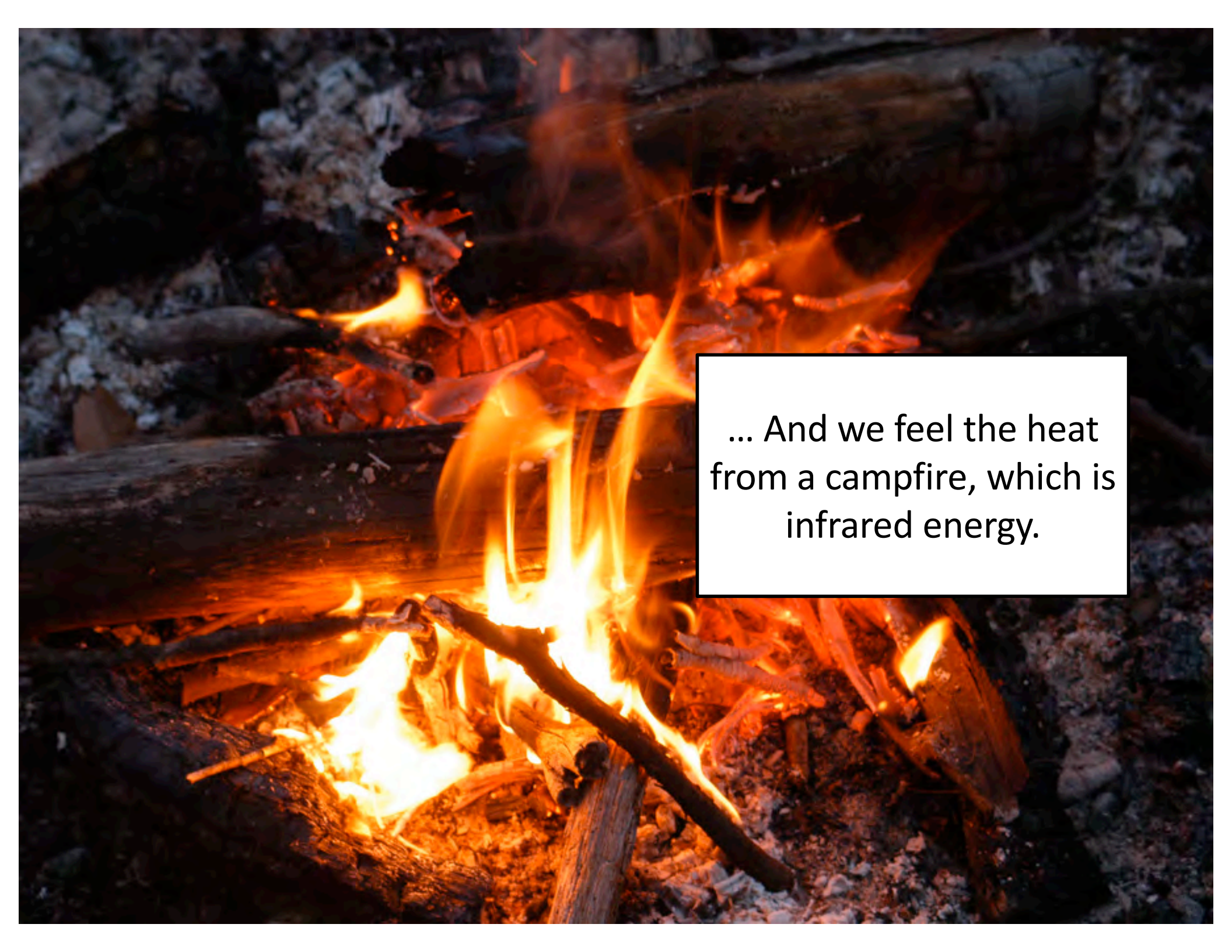
Did you know?: The amount of sunlight that reaches the Earth is equal to approximately 60w light bulbs for every square meter of the surface.

approximately 60w light bulbs for every square meter of the surface.  
Did you know?: The amount of sunlight that reaches the Earth is equal to



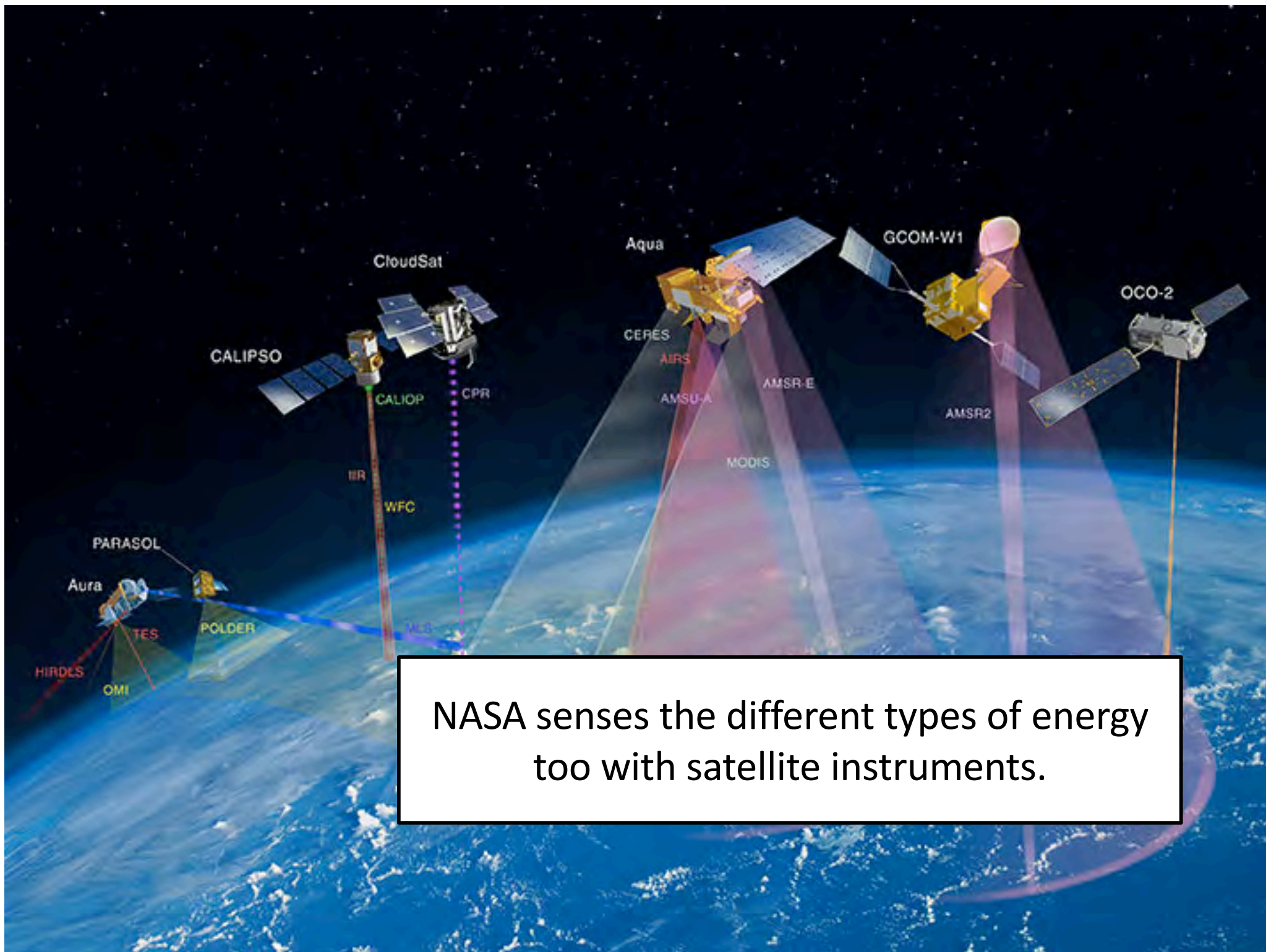
We can sense that energy in different ways. We see the things around us because of visible light...



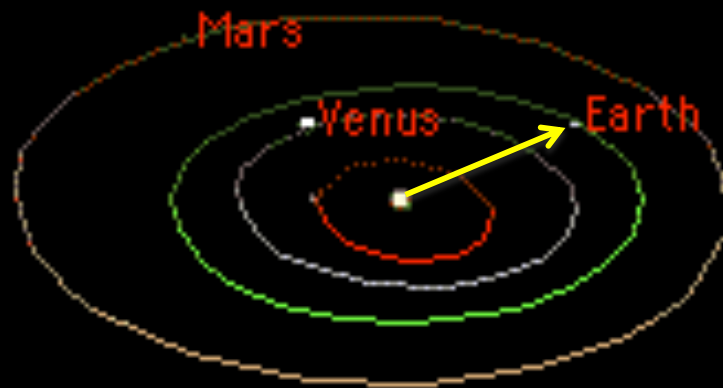


... And we feel the heat  
from a campfire, which is  
infrared energy.



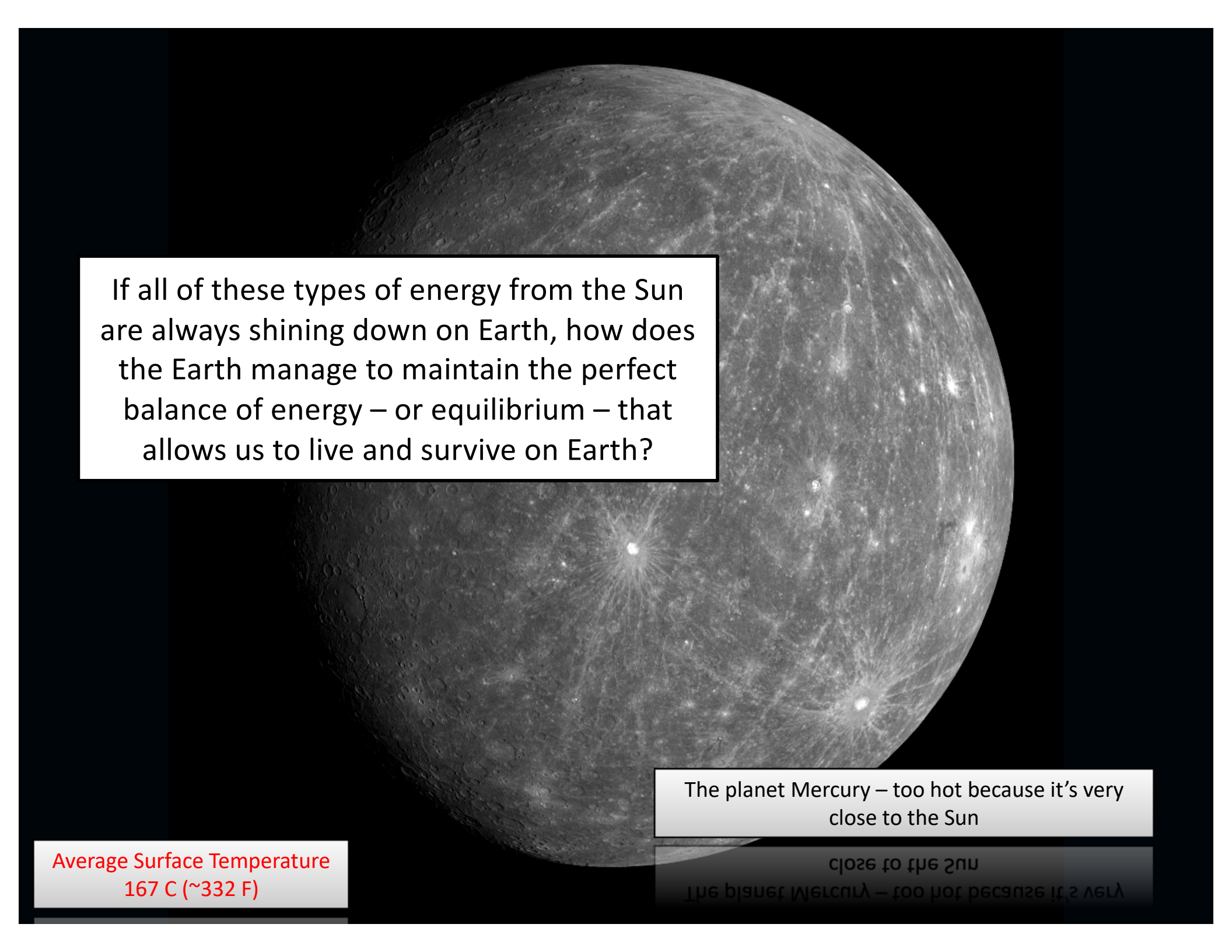


If all of these types of energy from the Sun are always shining down on Earth, how does the Earth manage to maintain the perfect balance of energy – or equilibrium – that allows us to live and survive on Earth?



The Sun – hot though it is - is a tiny part of Earth's environment. The rest is cold, dark space.

environment. The rest is cold, dark space.  
The sun – hot though it is - is a tiny part of Earth's

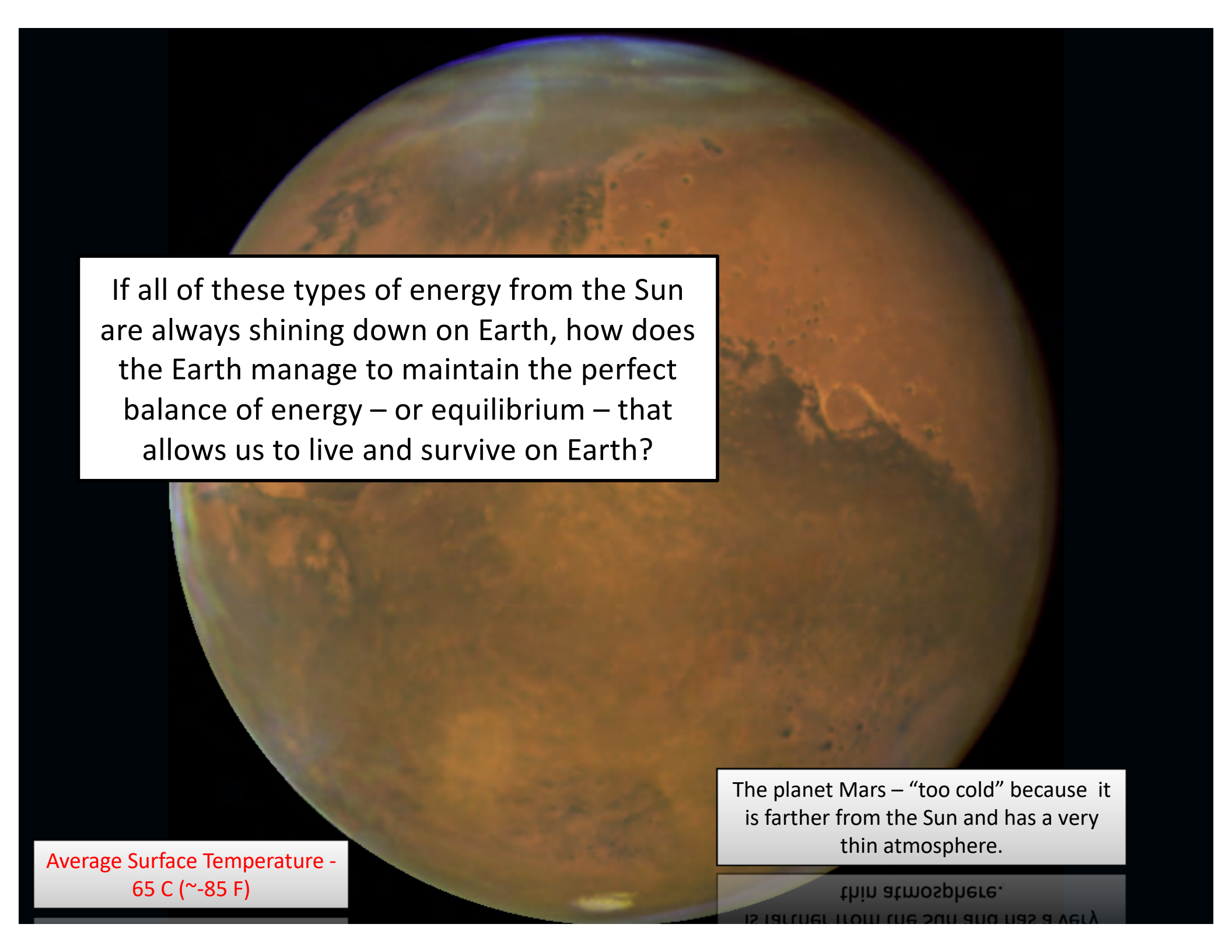


If all of these types of energy from the Sun are always shining down on Earth, how does the Earth manage to maintain the perfect balance of energy – or equilibrium – that allows us to live and survive on Earth?

Average Surface Temperature  
167 C (~332 F)

The planet Mercury – too hot because it's very close to the Sun

The planet Mercury – too hot because it's very close to the Sun



If all of these types of energy from the Sun are always shining down on Earth, how does the Earth manage to maintain the perfect balance of energy – or equilibrium – that allows us to live and survive on Earth?


Average Surface Temperature -  
65 C (~-85 F)

The planet Mars – “too cold” because it is farther from the Sun and has a very thin atmosphere.

thin atmosphere.

is farther from the sun and has a very






If all of these types of energy from the Sun are always shining down on Earth, how does the Earth manage to maintain the perfect balance of energy – or equilibrium – that allows us to live and survive on Earth?

Average Surface Temperature -  
18 C (~64 F)

3<sup>rd</sup> rock from the Sun. Still too cold for life.

11<sup>th</sup>  
3<sup>rd</sup> rock from the Sun. Still too cold for

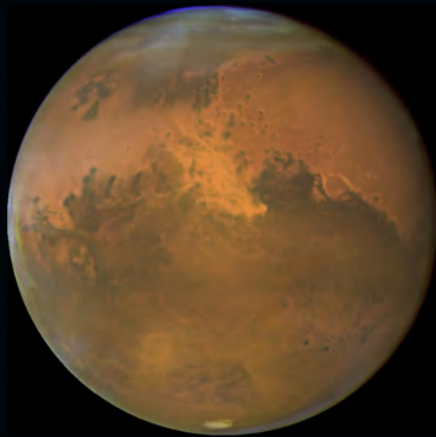


If all of these types of energy from the Sun are always shining down on Earth, how does the Earth manage to maintain the perfect balance of energy – or equilibrium – that allows us to live and survive on Earth?

Average Surface Temperature  
15 C (~59F)

The planet Earth with its atmosphere – just the right balance for life to survive and thrive.





The temperatures of Earth and all the planets are determined by their “Energy Budget.”

A 3D illustration of Earth from space. A large, bright yellow beam of solar radiation originates from the top left, representing the Sun, and points towards the Earth's surface. The beam passes through a small white cloud. The Earth's surface is depicted with green land and blue oceans. The sky is a gradient of blue. A white text box is in the upper right, and the title 'Earth's Energy Budget' is at the bottom.

First, energy enters the Earth system from the Sun.

## Earth's Energy Budget

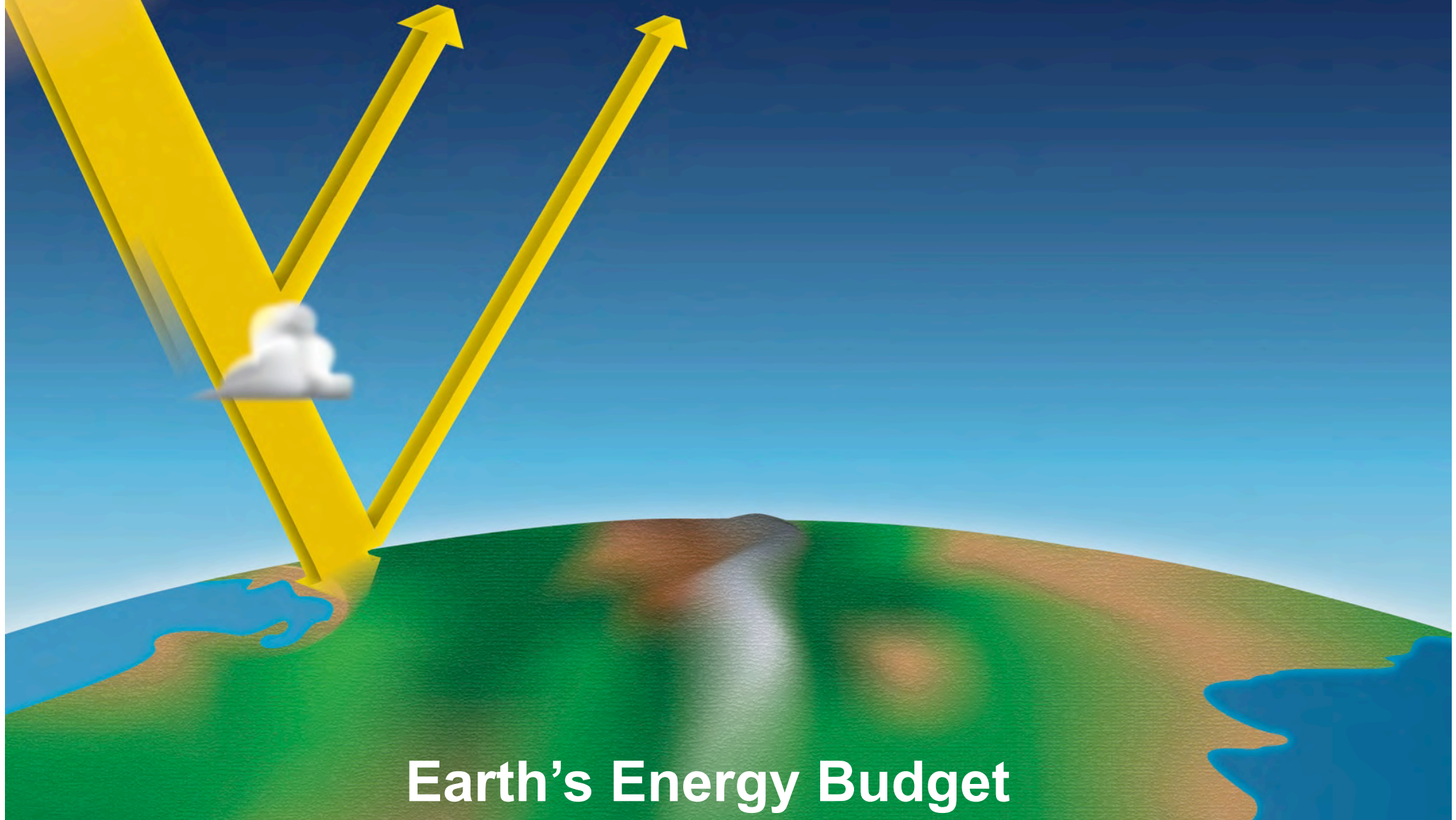


Some of that energy reflects off of clouds, dust, and other particles and never makes it to Earth's surface. Most of that energy, however, does get to the surface, and once it gets there, the ground, trees, and everything else around us can absorb the energy.

A 3D diagram illustrating Earth's energy budget. A bright yellow sun is in the top left corner, emitting a thick yellow beam of light. This beam is split into two paths: one path is reflected upwards by a white cloud, and the other path hits the Earth's surface. The Earth is depicted as a curved horizon with green land and blue water. The sky is a gradient of blue. The text 'Earth's Energy Budget' is at the bottom.

**Earth's Energy Budget**

However, there are some parts of Earth's surface that are highly reflective, like ice or snow, so in addition to absorbing energy, it also bounces off of those surfaces and heads right back out into space.



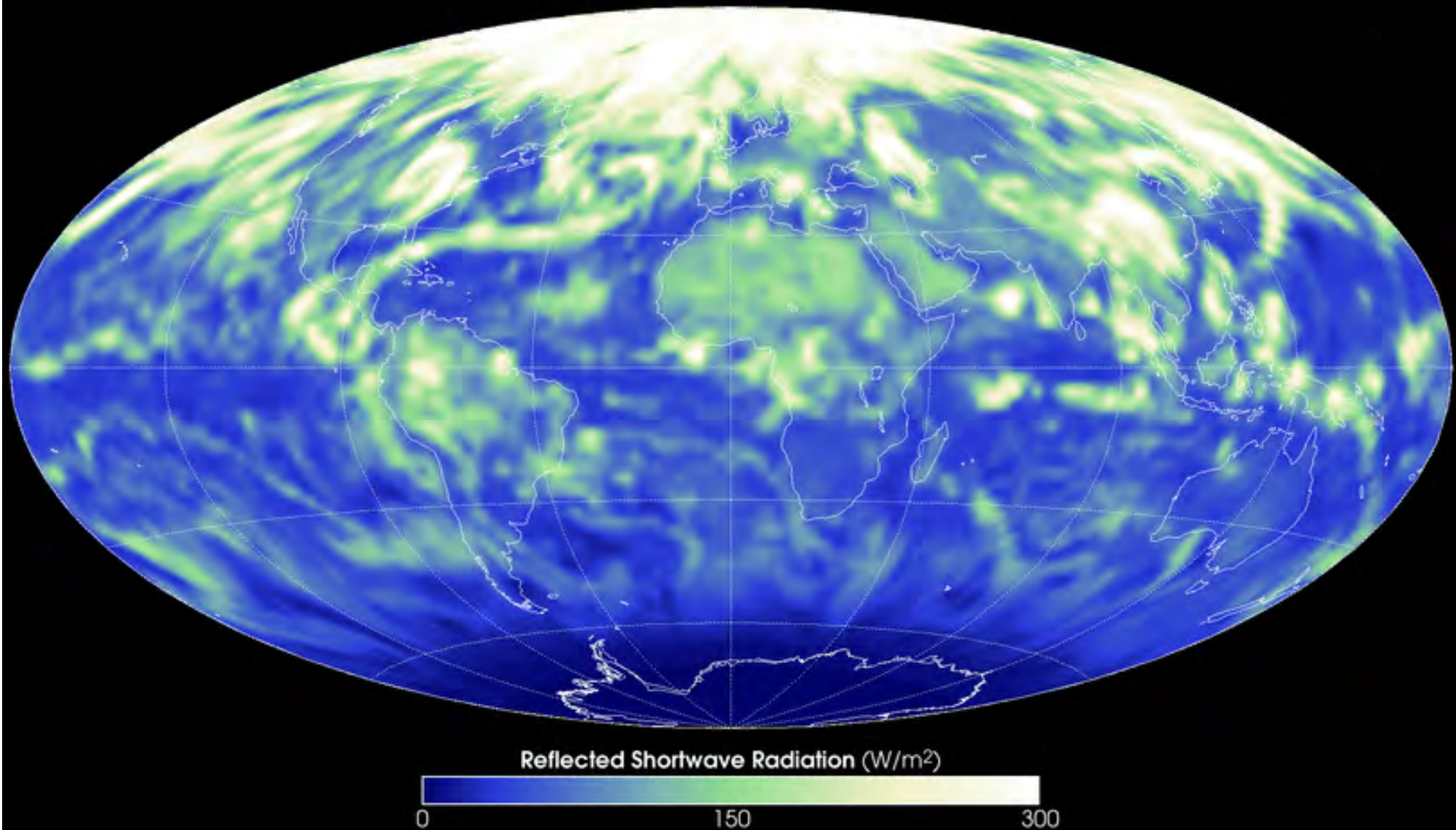
**Earth's Energy Budget**



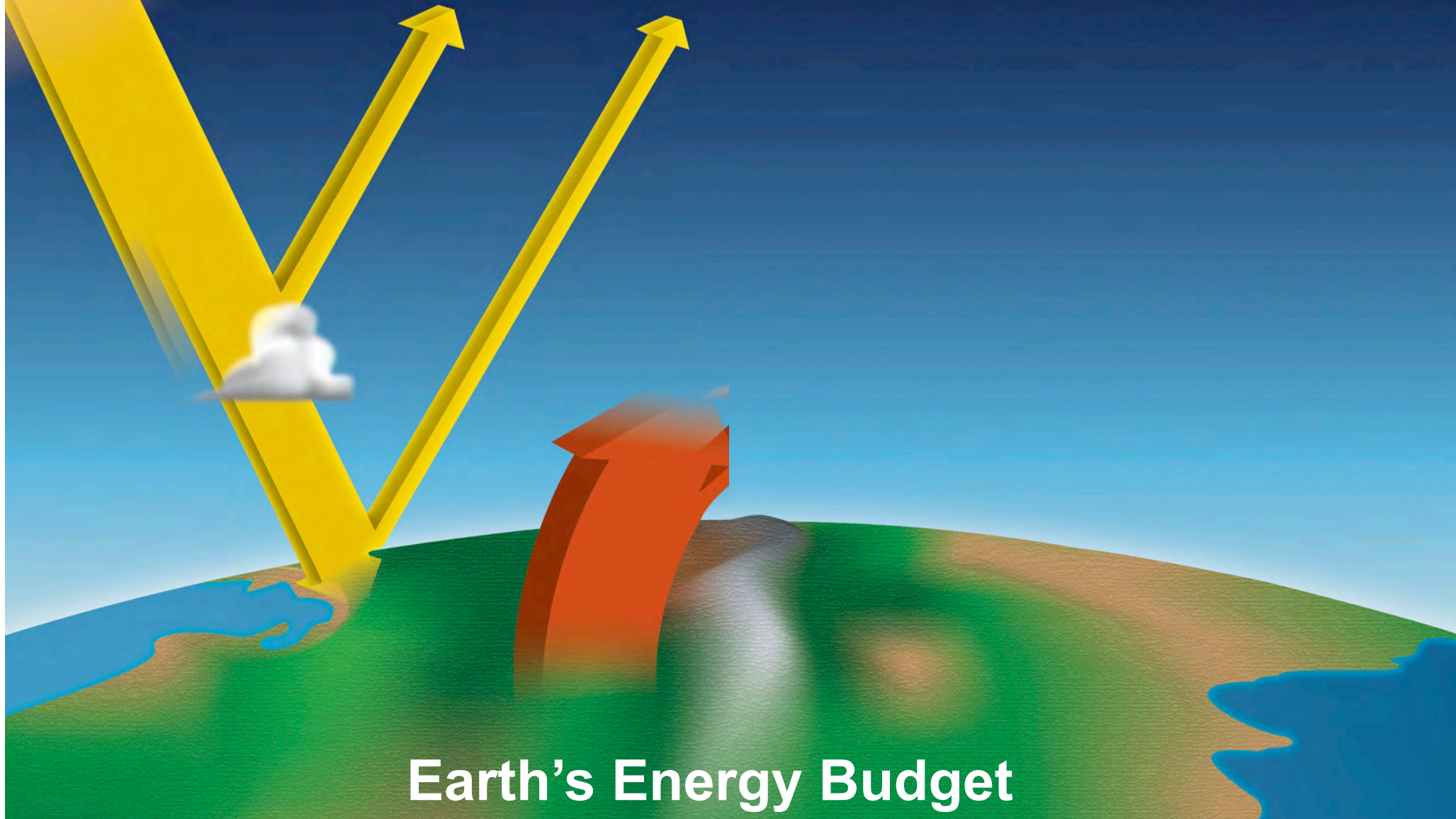
The world in reflected sunlight, May 25, 2001. Clouds, deserts and Arctic ice are bright. The south pole is in winter darkness with no sunlight to reflect.

Clouds and the Earth's Radiant Energy System (CERES)

May 25, 2001



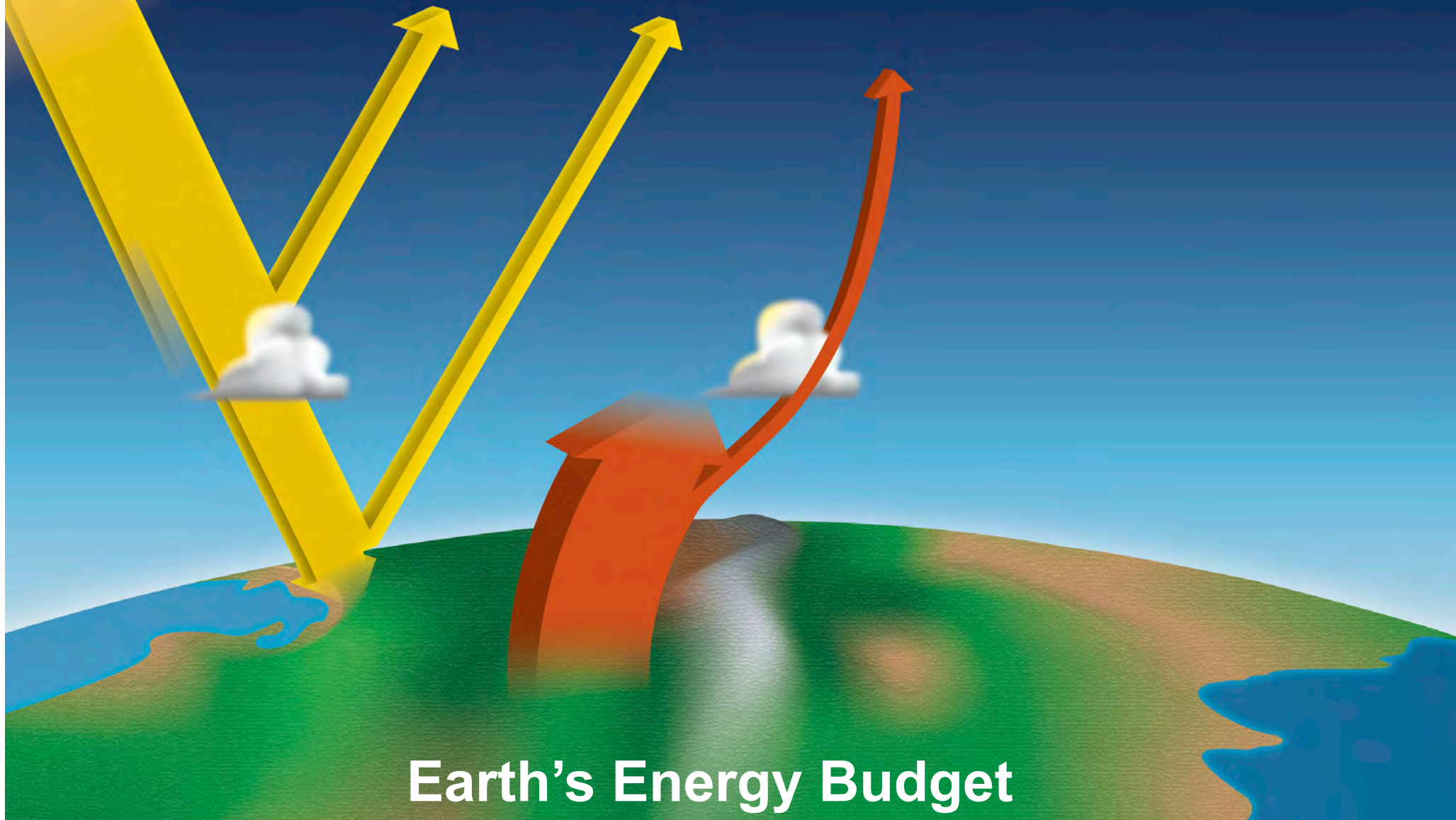
All of that energy that is absorbed by the Earth doesn't just stay there and build up forever. The Earth system radiates that energy out towards space as heat. Cold objects emit less energy; warm objects emit more.



**Earth's Energy Budget**



Most of the heat emitted from the surface is stopped on its way back out. Clouds and certain gases in the atmosphere absorb the energy, preventing it from leaving the system. Only a small window allows direct escape.



**Earth's Energy Budget**

Energy emitted from those clouds and gases goes in all directions. Some comes back to further warm the Earth. This is the greenhouse effect.





Finally, the surface energy budget is balanced by thermals and evaporation.



**Earth's Energy Budget**

Together all of these forms of incoming and outgoing energy have resulted in just the right living conditions for us on Earth.



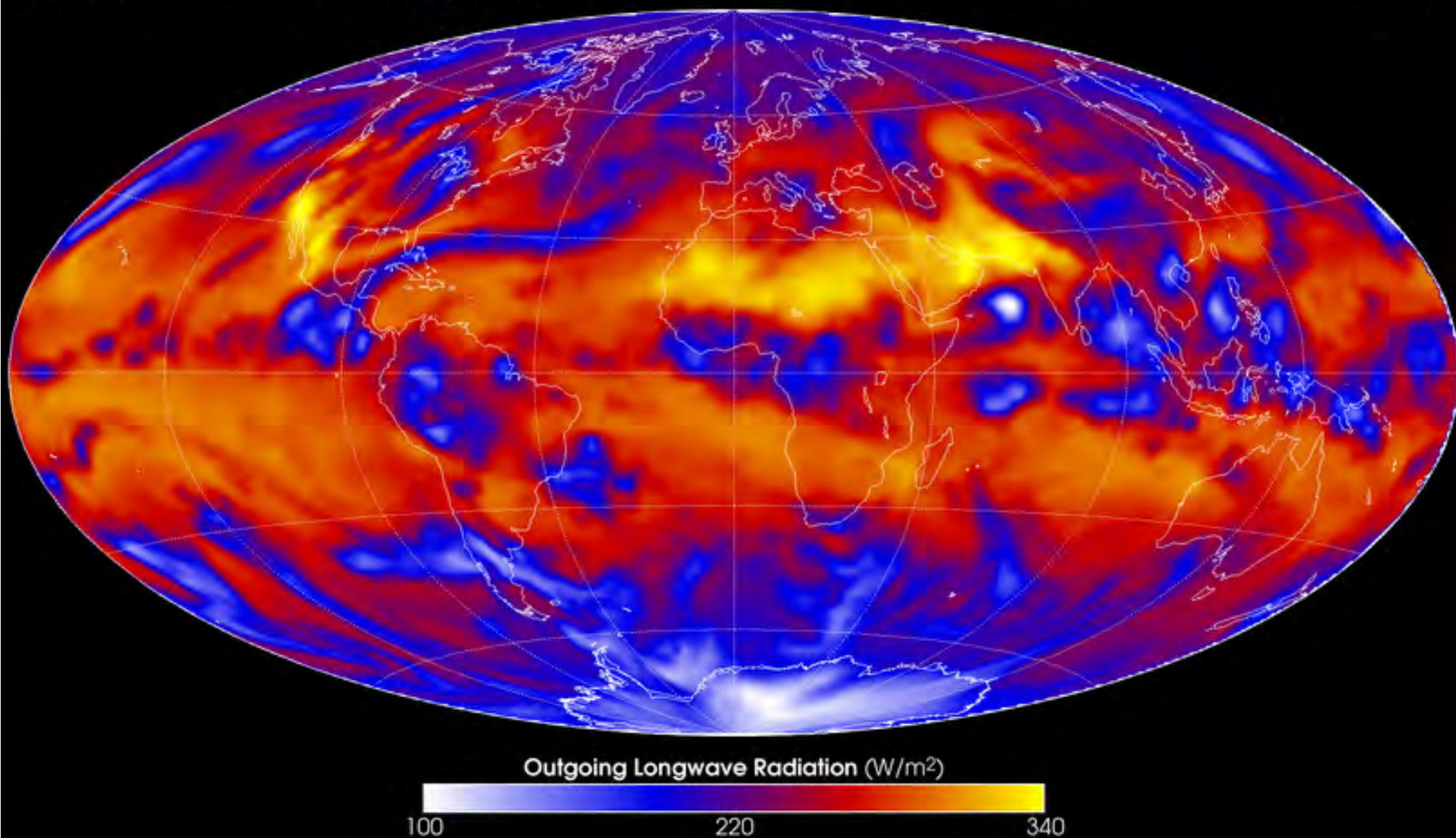
**Earth's Energy Budget**



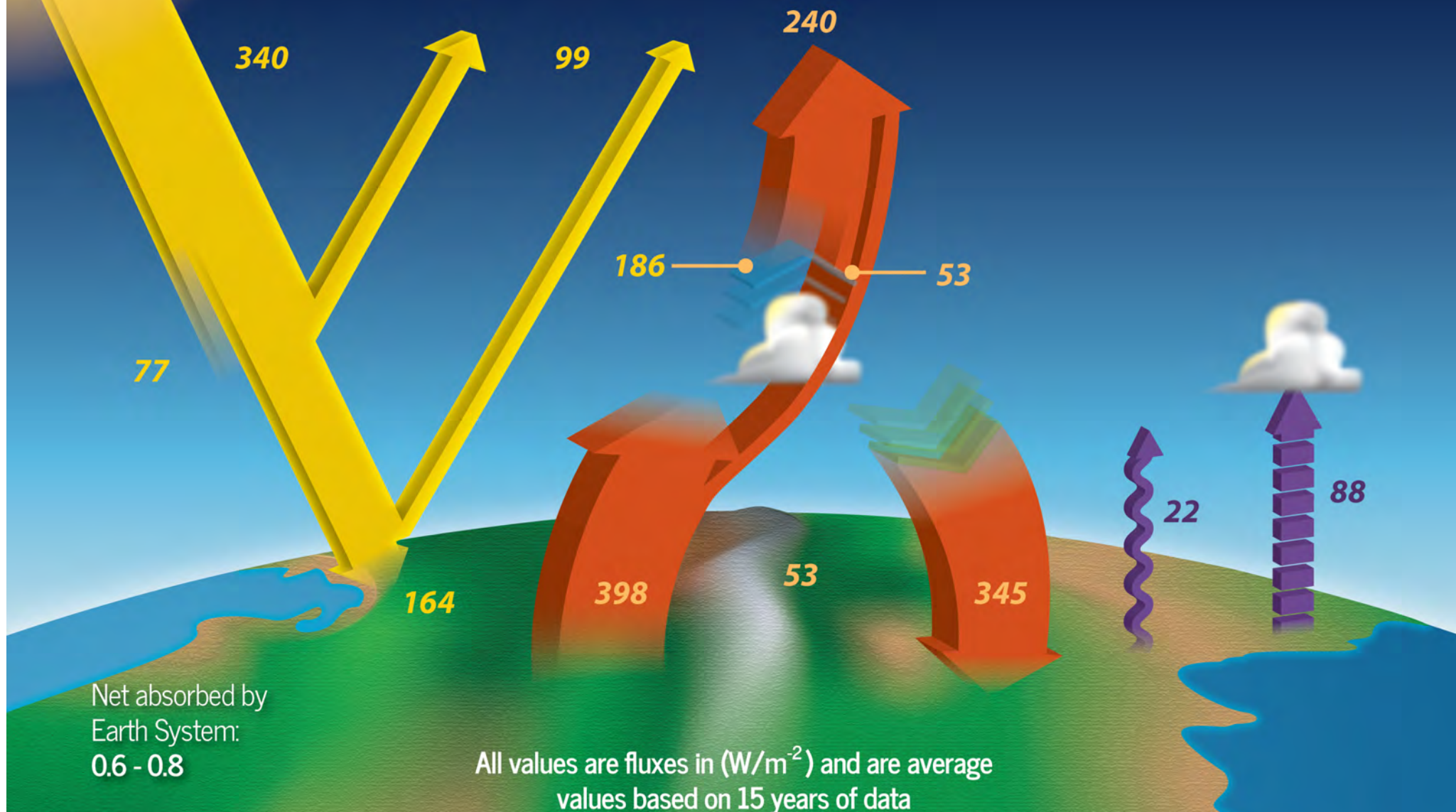
The world in emitted heat, May 25, 2001. Deserts are hot; clouds and polar ice are cold. The south pole is in winter deep freeze.

Clouds and the Earth's Radiant Energy System (CERES)

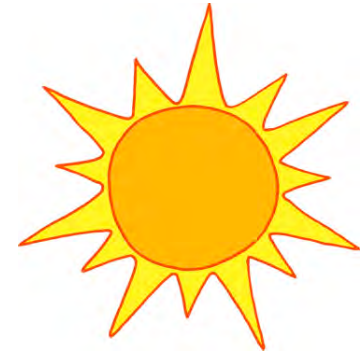
May 25, 2001



Scientists use satellites, ground-based instruments, aircraft field campaigns, and computer models to determine the magnitude of each flux.

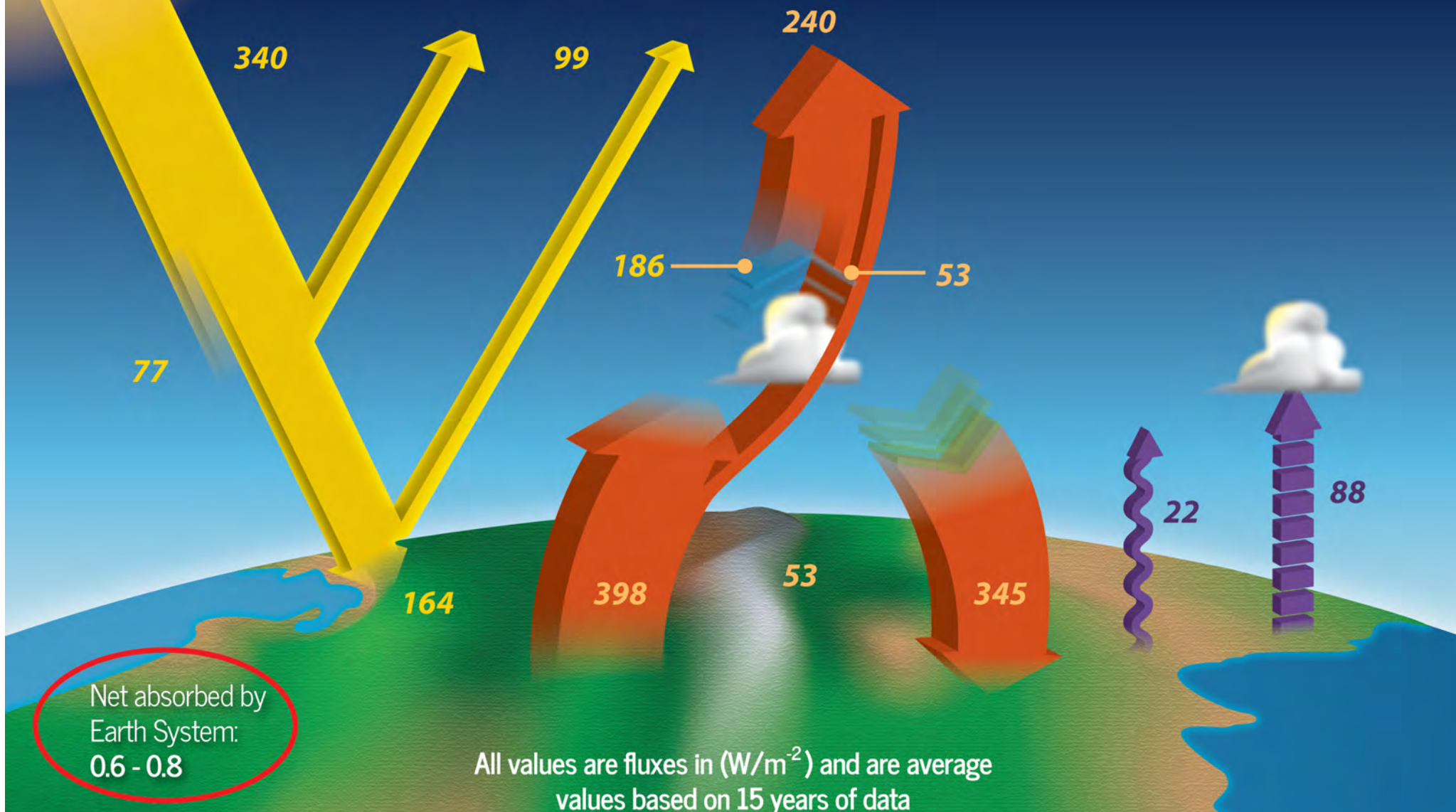






Like your house, anything that increases or decreases the amount of incoming or outgoing energy would disturb Earth's energy balance and would cause global temperatures to rise or fall.

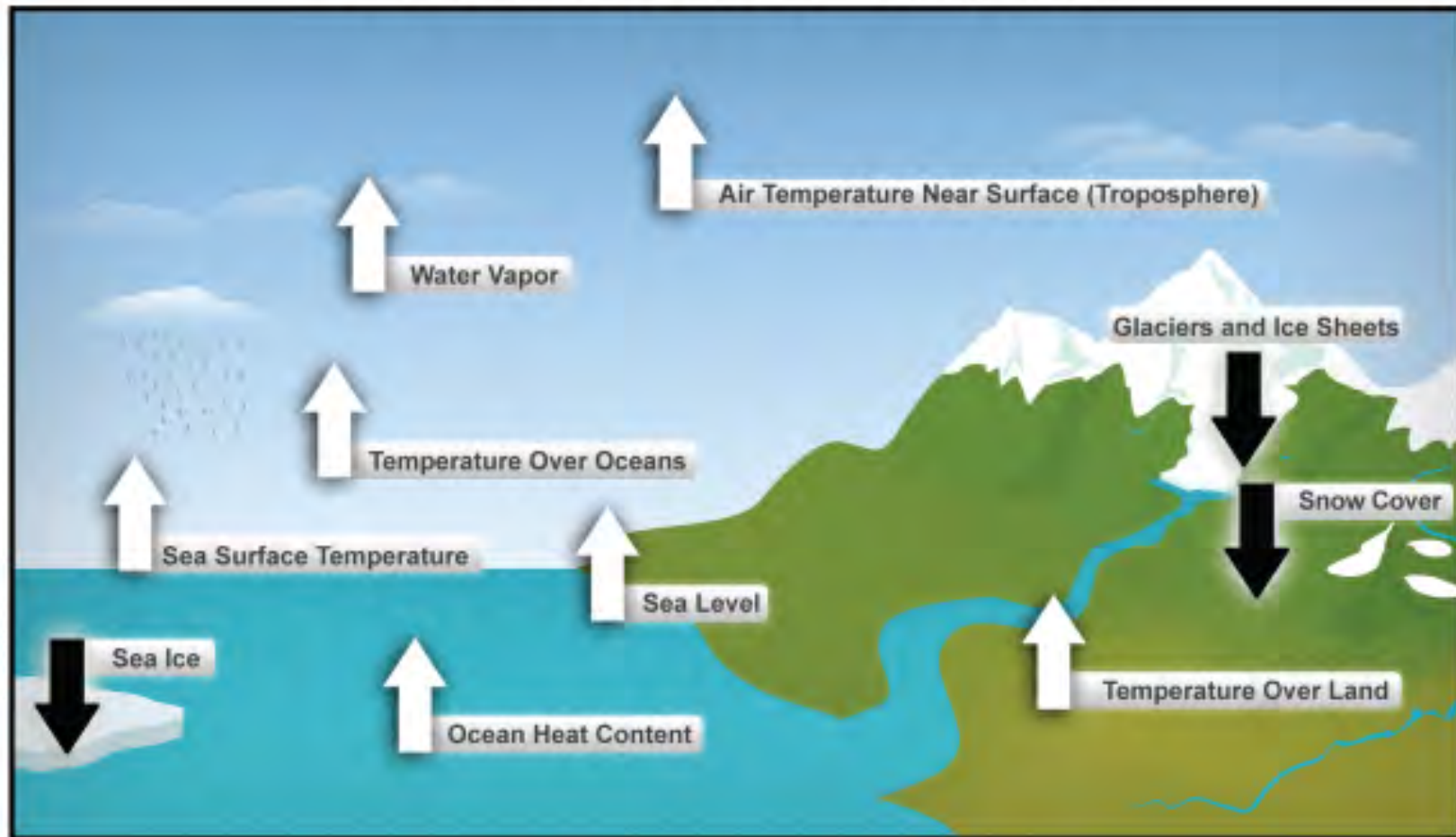
Over the last decade, our best estimate is that there is a small positive imbalance in Earth's energy budget.





This is consistent with several other *lines of evidence* of a warming planet.

## Ten Indicators of a Warming World



<https://www.globalchange.gov/browse/multimedia/ten-indicators-warming-world>

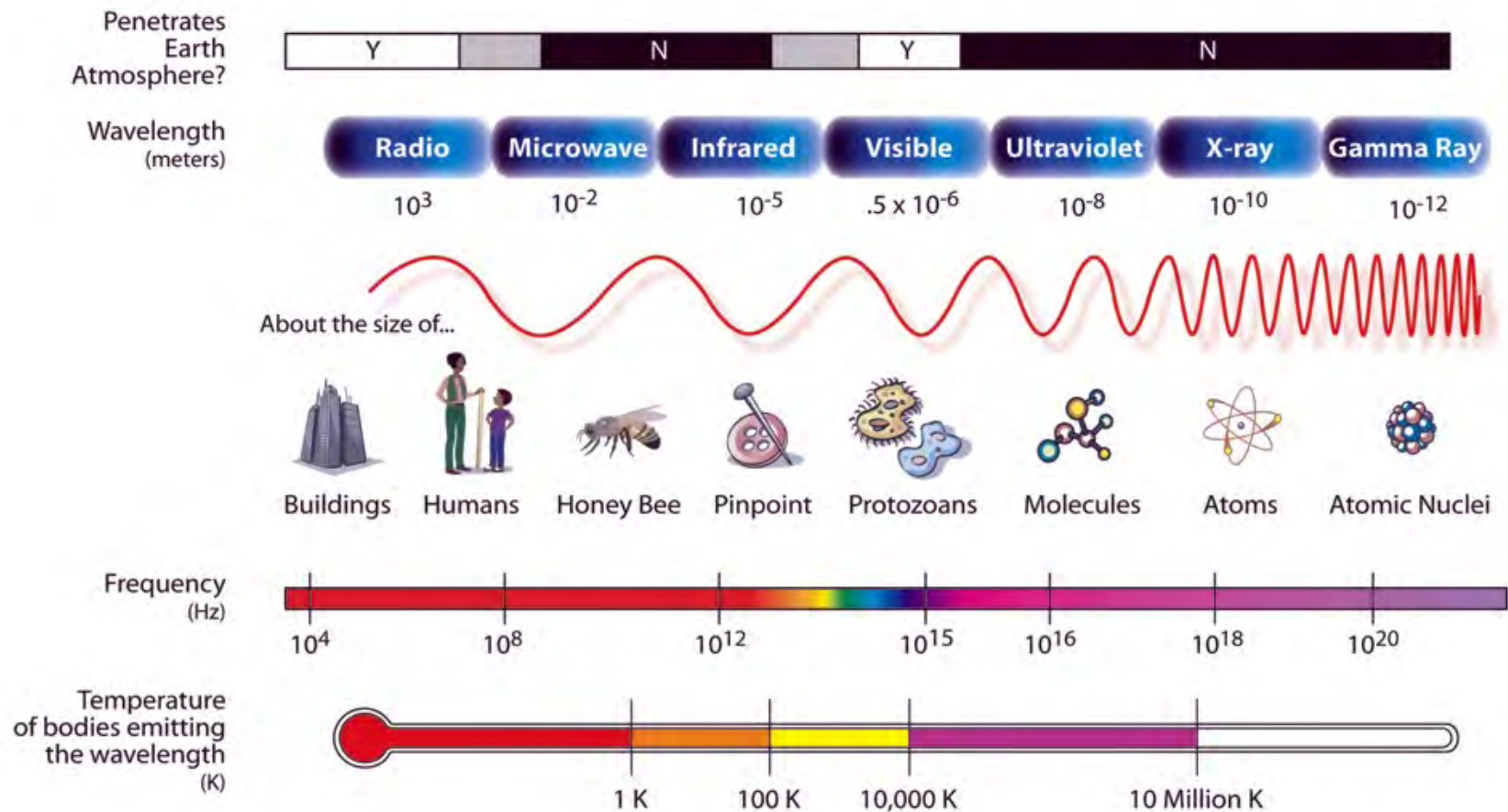
The End  
... for now



Details behind the story

# Teaching Resources: The Electromagnetic Spectrum

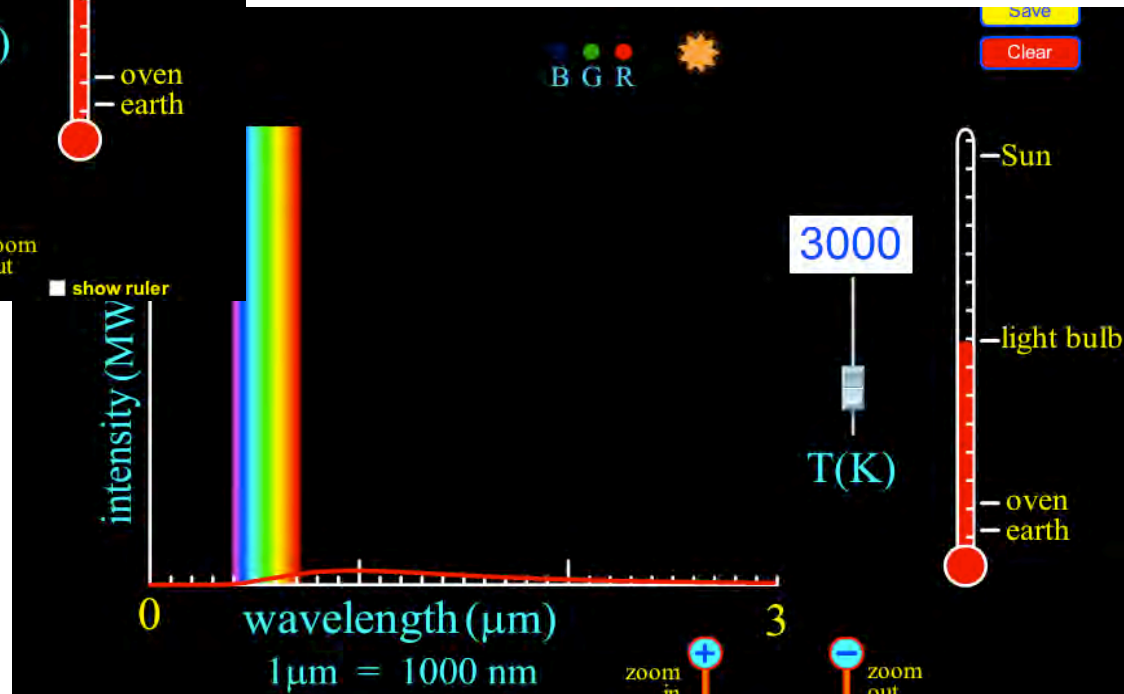
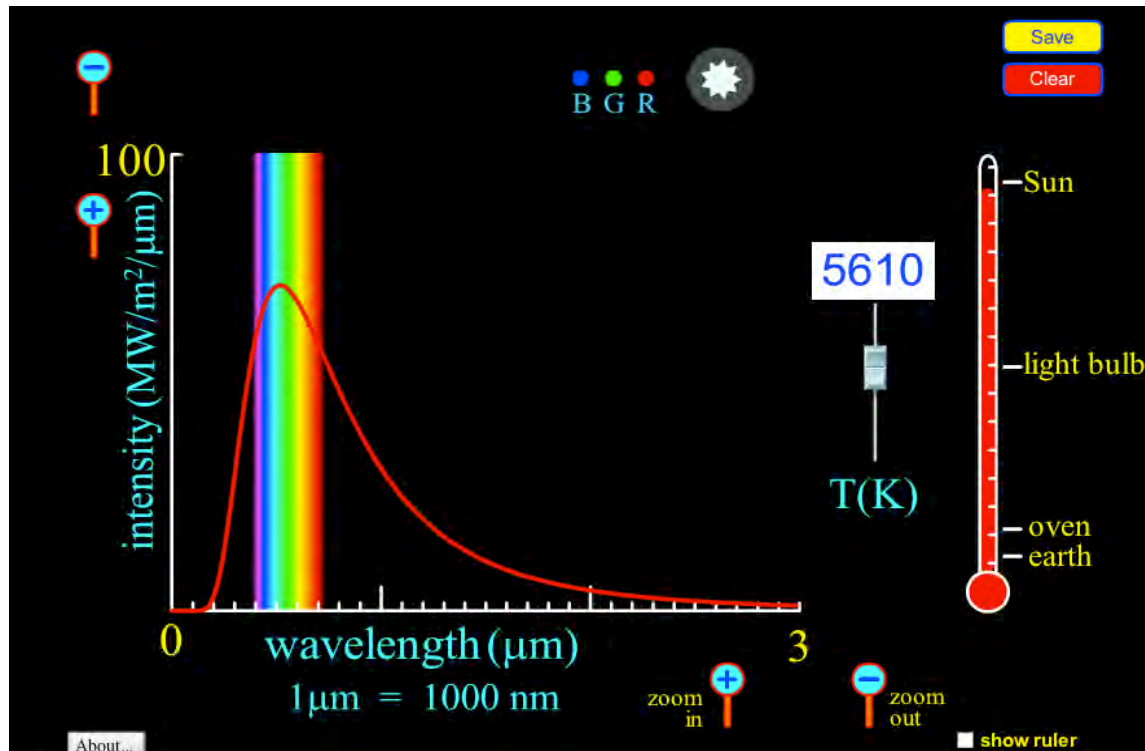
## THE ELECTROMAGNETIC SPECTRUM



<https://myasadata.larc.nasa.gov/basic-page/electromagnetic-spectrum-diagram>



# The Blackbody Spectrum



<https://phet.colorado.edu/en/simulation/blackbody-spectrum>

# Equil Temp Calculation – An Equation!

$$\text{Equil Temp} = \text{Temp}_{\text{star}} * (1 - \text{albedo})^{1/4} * \text{Square root} \left( \frac{\text{Radius}_{\text{star}}}{2 * \text{Distance}} \right)$$

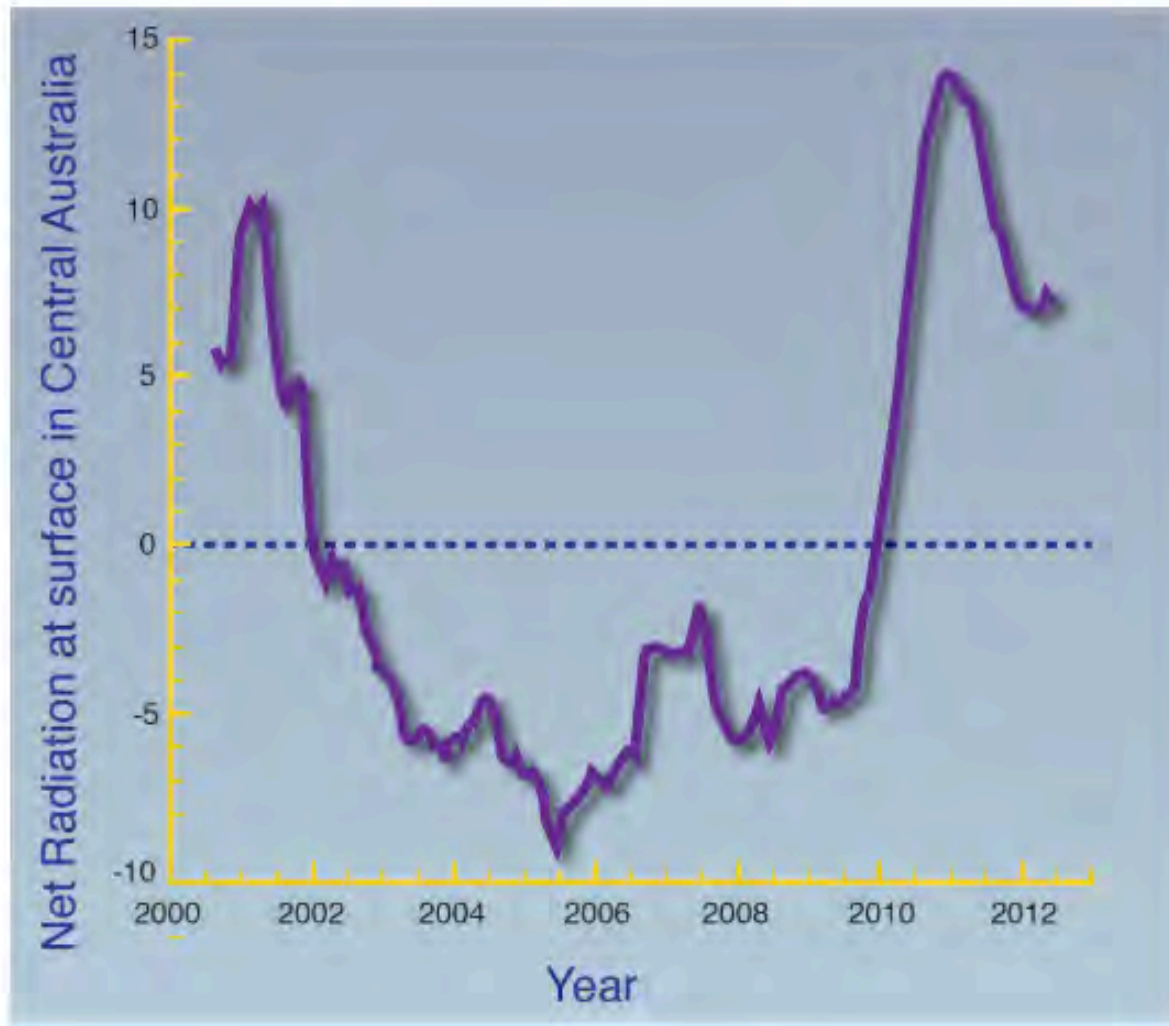
<b>Temp<sub>Sun</sub> ~ 5778K</b>	<b>Radius<sub>Sun</sub> ~ 695,500 km</b>
Albedo ~ 0.3	Distance ~ 149,600,000 km

For Earth: Equil Temp ~254 K = -18 Celsius



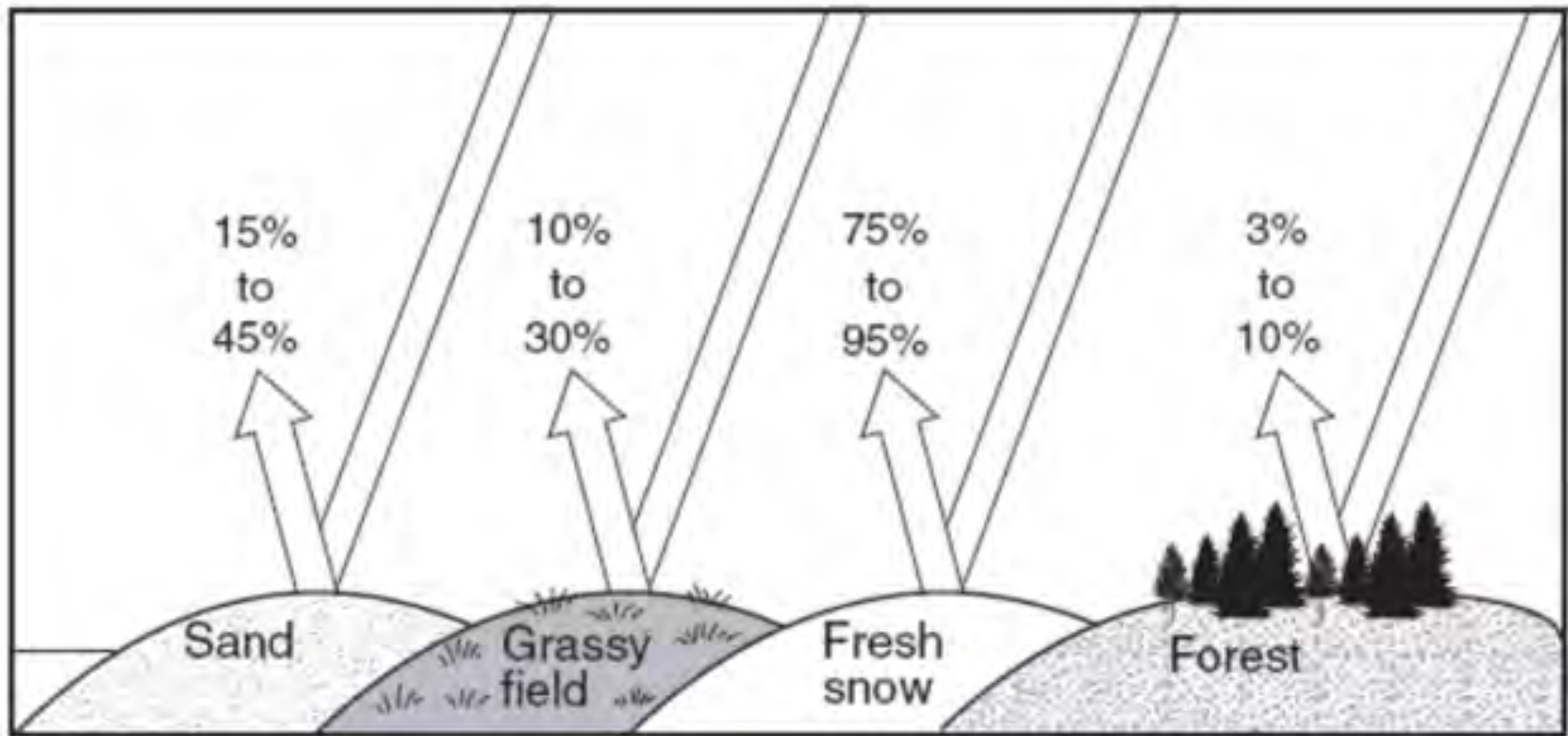
# Energy Budget Mini Lesson

CASE STUDY: Surface Effects on Energy Budget - Changes in Central Australia



<https://mydasdata.larc.nasa.gov/maps-graphs-and-data/earths-energy-budget>

# Curriculum Unit Plan



[Unit: Earth's Energy Budget](#)



# Greenhouse Effect



<https://www.youtube.com/watch?v=b3NFfWlfj24>

# Teaching Resources

[http://science-edu.larc.nasa.gov/energy\\_budget/](http://science-edu.larc.nasa.gov/energy_budget/)

## The Story of Energy in the Earth System

The Sun is the source of energy for the Earth system. This energy reaches the Earth primarily in the form of visible light, although it also includes some infrared energy (heat), ultraviolet energy, and other wavelengths of the electromagnetic spectrum. Taking into account night and day and the seasons, on average about 340 Watts of energy enter every square meter of the Earth system. This is slightly less than the energy that six 60 Watt light bulbs would produce, again, for every square meter of the Earth.

As it reaches the Earth system, some of the sunlight is reflected back to space by clouds and the atmosphere (particularly dust particles or aerosols in the atmosphere). A little more sunlight is reflected to space from the Earth surface, particularly from bright regions such as snow- and ice-covered areas. In total, about 30% of sunlight is reflected directly back to space. This percentage is called the albedo.

About 70% of the sunlight is absorbed by the Earth system (atmosphere and surface) and heats it up.

The elements of the Earth system (surface, atmosphere, clouds) emit infrared radiation according to their temperature, following the Planck function ([http://phet.colorado.edu/simulations/sims.php?sim=Blackbody\\_Spectrum](http://phet.colorado.edu/simulations/sims.php?sim=Blackbody_Spectrum)). Cold objects emit less energy; warm objects emit more. This infrared radiation is emitted in all directions.

One net effect of all the infrared emission is that an amount of heat energy equivalent to ~70% of the incoming sunlight leaves the Earth system and goes back into space. This is because the Earth system constantly tends toward equilibrium between the energy that reaches the Earth from the Sun and the energy that is emitted to space. Scientists refer to this process as Earth's "radiation budget", and it happens because the system tends toward equilibrium.

Another net effect of the infrared emission is that about 340 Watts of infrared energy is directed back to the surface from the atmosphere. This is called the greenhouse effect, and is due mainly to water vapor in the atmosphere. Carbon dioxide, methane and other infrared-absorbing gases enhance this effect. Without an atmosphere, the Earth would have an average temperature of -18 °C, too cold for life as we know it.

At the surface, two additional heat transfer mechanisms operate to balance the system, in addition to the radiation transfer: 1) convection and conduction in the form of thermals (which create weather), and 2) a change of state of water through evapotranspiration (which also feeds weather).

### Bottom Line:

According to the best available data from the CERES satellite instrument, along with information from other data sources, the radiation budget at the top-of-atmosphere was not balanced during the five years from 2000-2005. Approximately 0.85 Watts of energy were added to the Earth system, on average, for each square meter of the Earth's surface. A continued imbalance of the radiation budget would mean a change in Earth's climate.

## Balancing the Energy Budget

Just like a family budget for finances, the energy budget of the Earth should be balanced. In equation form:

$$\text{Energy In} = \text{Energy Out}$$

This balance can be considered at several levels in the Earth system:

At the top of the atmosphere, the energy coming in from the Sun is balanced by sunlight reflected back to space and the net infrared emission from the Earth. The equation is:

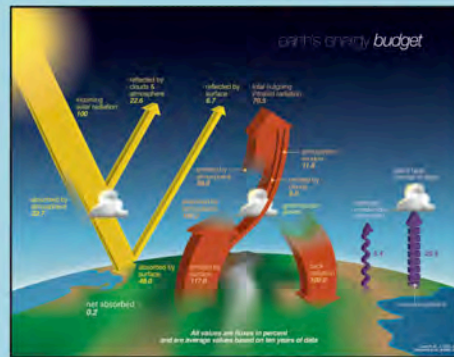
$$\text{Sunlight In} = \text{Sunlight reflected from clouds/atmosphere} + \text{Sunlight reflected from surface} + \text{IR emission}$$

At the Earth's surface, absorbed sunlight is balanced by the net IR emission and the conduction/convection and evapotranspiration. The equation is:

$$\text{Sunlight absorbed} + \text{IR back radiation (greenhouse effect)} = \text{IR emission} + \text{Thermals} + \text{Evapotranspiration}$$

The most complicated balance is in the atmosphere, where absorbed sunlight and energy absorbed from the surface are balanced by the net infrared emission. The equation is:

$$\text{Sunlight absorbed} + \text{IR absorbed} + \text{Thermals} + \text{Evapotranspiration} = \text{IR emitted to space} + \text{IR emitted to ground}$$



These balance equations are for an equilibrium state of the Earth. Equilibrium would be expected for a planet that has spent a long time in a stable solar system, but sometimes changes occur that take the system out of balance. For example, the ice ages occurred because of long-term changes in Earth's orbit around the Sun, which resulted in a change to the "Sunlight In" term. Over time, reflected sunlight and IR emission changed to balance the first equation. The result was a colder surface and major glacial advances.

## Energy Budget Changes Since 1950

In more recent years, changes in the atmosphere have also caused unbalance in these equations, with another departure from equilibrium. At least part of these changes is due to human activities.

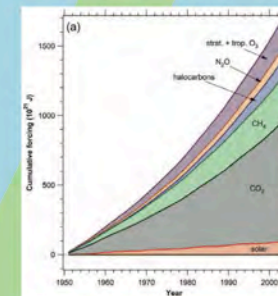


Figure (a) depicts items that have caused changes in the energy budget since 1950. Called forcing agents, these absorb additional energy in the atmosphere (enhanced greenhouse effect). The greenhouse gases shown in the figure:

carbon dioxide - CO<sub>2</sub>  
methane - CH<sub>4</sub>  
halocarbons  
nitrous oxide - N<sub>2</sub>O  
stratospheric + tropospheric ozone - O<sub>3</sub>

have increased in the atmosphere mostly due to human activities. A natural change from variations in the Sun's output is also shown along the bottom of the graph. This figure shows the cumulative effect of small changes. The additional heat trapped each year continues to add up to a warmer Earth.

Knowing how much additional heat was absorbed (because we know how much of these gases were emitted) the question becomes: where did the energy go? Figure (b) partitions the added energy shown above based on observed changes in the Earth system. So far, a small amount of the energy has gone into warming the ocean - the part of the Earth that stores the most energy. Some has escaped Earth in the form of increased IR emission because of warmer temperatures. Some was reflected to space by aerosols (mostly volcanic in origin) in the atmosphere. The remainder (white band) is inferred to have been reflected due to aerosols (mostly pollution) in the troposphere, and other effects such as a changing reflection of the land surface due to deforestation, for example.

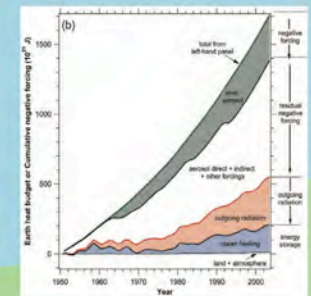


Figure from Murphy et al., 2009 in Geophysical Research Letters



# More Background Resources

[https://science-edu.larc.nasa.gov/energy\\_budget/links.html](https://science-edu.larc.nasa.gov/energy_budget/links.html)

## Radiative Forcing

[Climate Forcings and Global Warming](#)

## Radiation Budget

[Earth Observatory: Climate and Earth's Energy Budget](#)

[MY NASA DATA Mini Lesson](#)

[MY NASA DATA Seasonal Cycles](#)

[NASA GISS-ICP: Global Equilibrium Energy Balance Interactive Tinker Toy \(GEEBTT\)](#)

[NASA GISS High School Unit Plan \(PDF\)](#)

[PBS Learning Media: Earth's Delicate Energy Balance](#)

[PBS Learning Media: Clouds and Earth's Energy Balance Audio Interview \(Bruce Wielfeld\)](#)

[UCARConnect: Tracking Earth's Energy Flow](#)

[UCAR: Earth's Energy Balance Interactive](#)

[Aqua CERES: Tracking Earth's Heat Balance](#)

[How CO<sub>2</sub> Warms The Climate - Ray Pierrehumbert](#)

[eClips Real World Video](#)

[Global Energy Balance Animated Diagram](#)

## Atmospheric Layers

[Layers of the Earth's Atmosphere](#)

[Atmosphere layers - Encyclopedia of Earth](#)

## General Information

[NASA LaRC Science Directorate Home Page](#)

[NASA LaRC CERES Home Page](#)

# Teaching Resources: Explore Data

[Earth System Data Explorer](#)

